
Chemical Quality and Indicator Parameters For Monitoring Landfill Leachate in Illinois

Thomas P. Clark
and Rauf Piskin

Illinois Environmental Protection Agency
Division of Land/Noise Pollution Control
2200 Churchill Road
Springfield, Illinois 62706, U.S.A.

ABSTRACT / Evaluation of analyses of leachate for inorganic constituents, from selected landfills in Illinois indicates that leachate quality is variable and is strongly affected by waste type and cover material. Twenty parameters were detectable in all samples, but selenium was not detected in any of the samples analyzed. More than 98% of the mean leachate composition was comprised, in descending order, of total alkalinity (bicarbonate plus carbonate), sulfate, sodium plus potassium, calcium plus magnesium, chloride, and iron plus manganese. Excluding iron, trace metals contributed less than one percent to the total; of these, copper, zinc and boron were most significant.

Based on milliequivalents per liter of major constituents, approximately 73 percent of the cations and 92% of the anions fall within the concentration range of potable waters. Heavy metals, organics, suspended matter, microorganisms, odor and color are among the objectionable qualities of leachate which should not be present in potable waters.

In assessing the impact of leachate on ground-water quality, use of indicator parameters in place of comprehensive analyses for routine water samples is frequently desirable in the interest of both time and economics. Availability, mobility, persistence, analyticity and contrast of concentrations in leachate and ground water are important factors to consider in selection of an indicator. Boron, iron, ammonia and total dissolved solids appear to be reliable parameters for indicating ground-water pollution by leachate. Chloride and hardness may also be useful under certain conditions. Sulfate was the least reliable parameter considered. Although many of the trace elements in leachate exceed Illinois Environmental Protection Agency Public Water Supply Standards in more than 50% of the samples, these elements are most useful as indicators when a waste rich in trace elements is deposited in a landfill of unfavorable hydrogeology.

Introduction

Landfilling is currently the most widely employed waste disposal method. It is well known that landfills can cause environmental problems. Of these, water pollution, especially ground-water pollution, is the most important. Water pollution is caused by the migration of leachate from landfills to known or potential water resources. Leachate, a liquid formed by the percolation of water through landfilled wastes, contains suspended matter, pathogens and dissolved chemicals. Wastes deposited below the zone of saturation or into standing water will cause leachate generation in all climates; in humid climates as in Illinois, however, leachate is generated principally by the infiltration of a portion of precipitation through the final cover into the landfill, even when the base of the landfill is above the saturated zone. Although ground-water pollution from landfills can be considered "local", it may affect not only present and potential use of the impacted aquifer, but also the land above it, for a long time.

One of the important elements of ground-water pollution resulting from landfills is the quality of leachate generated. This paper discusses the quality of leachate from landfills in Illinois, and evaluates indicator parameters for monitoring leachate movement. Leachate analyses from the files of the Division of Land Pollution Control (DLPC) of the Illinois Environmental Protection Agency (IEPA) are the basic data of the study.

Previous Work

Several researchers have investigated quality of leachate under controlled laboratory and field as well as actual field conditions. These studies indicate that leachate quality depends upon the composition and age of refuse, its thickness and compaction, whether it is milled and covered, the amount of water in the land-

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fill, and the temperature in the cells. Leachate contains substantial amounts of dissolved organics (BOD, COD), inorganics, heavy metals, suspended matter and pathogens. High concentrations of calcium, sodium, potassium, magnesium, manganese, ammonium, chloride, sulfate, iron, zinc, BOD, COD, hardness and alkalinity have been reported in raw leachate.

Qasim and Burchinal (1970) indicated from their lysimeter tests that leachate was rich in both microorganisms and dissolved solids. Concentrations of measured parameters increased in the early phase of the test period, and later, decreased gradually within two to four weeks. BOD concentrations were 40 to 85 times higher in leachate than in most raw domestic sewage sludge. Furthermore, the pollutant load of the leachate generated per foot of refuse was inversely related to refuse column thickness. In another lysimeter study, Fungaroli (1971) reported that the mean pH of leachate was 5.5. Measured parameters were more concentrated during the early phase of the study, but varied considerably during the study. From this data, it is estimated that the total iron concentration varied between almost 0 and 1600 mg/l. Ranges for other constituents included: zinc, 0 to 135 mg/l; chloride, 50 to 2,400 mg/l; sodium, 100 to 4000 mg/l; hardness, 300 to 6000 mg/l; COD, 1000 to over 50,000 mg/l. Sizeable variations in nickel and copper concentrations were also reported.

Hughes and others (1971) studied four landfills in northeastern Illinois and also concluded that leachate quality was highly variable. Leachate contained larger pollutant loads than raw sewage or industrial waste. Concentrations of certain heavy metals sometimes were higher than the applicable drinking water standards. There was little correlation between chemical parameters in leachate and age of refuse from which leachate was generated. Chloride was found to be useful for determining the magnitude and direction of movement of

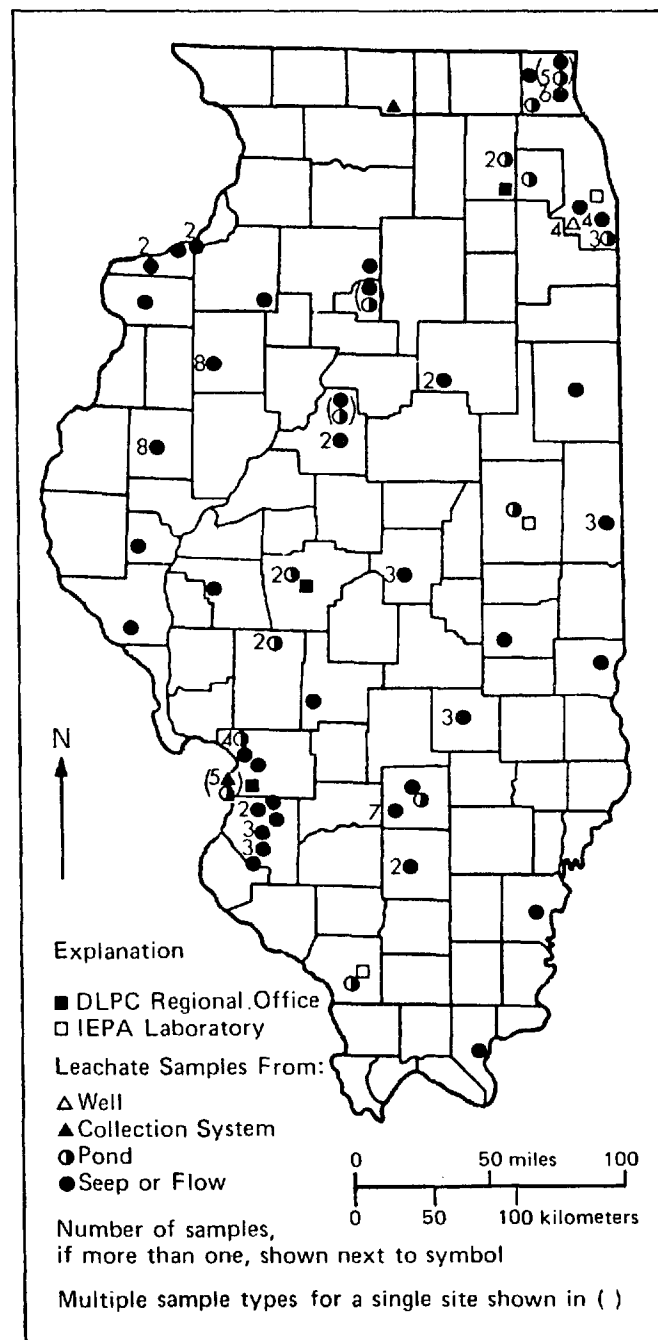


Figure 1. Location of leachate samples collected in Illinois

ground-water pollution due to landfill leachate.

Andersen and Dornbush (1972) concluded in their field study of a South Dakota landfill that chloride, sodium and specific conductance were the most useful parameters for indicating leachate contamination of ground water. BOD did not seem to be suitable as an indicator of contamination from organic material.

The United States Environmental Protection Agency (1973) summarized leachate analyses from different studies. They noted that leachate quality is variable, and stronger than raw sewage. Zenone and others (1975) reported that organic carbon, iron, manganese and dissolved solids were high in leachate from three landfills near Anchorage, Alaska. Variations in leachate quality were attributed to the age of refuse and local ground-water conditions. Kunkle and Shade (1976) indicated that leachate increased the concentrations of total hardness, alkalinity, calcium, magnesium, sodium, potassium and sulfate, and could also elevate ammonium, iron, COD and BOD in ground water.

Ham and Anderson (1975-1976) investigated quality of leachate from various controlled refuse cells for about two years. Concentrations of dissolved chemicals in leachate reached a peak in the early part of the test in milled and uncovered cells, then dropped off.

Leachate from the covered cell containing unprocessed refuse was stable compared with milled refuse deposited in an uncovered cell where leachate strength decreased rapidly after several months. Leachate pH was acidic (5 to near 7) and specific conductance ranged from about 2000 to 8000 micromhos/cm. Ranges reported for other leachate constituents were: COD, 2000 to 8000 mg/l; iron, 30 to 160 mg/l, chloride, 180 to 900 mg/l; phosphate, 4.6 to 62 mg/l; total hardness, 470 to 2250 mg/l; and alkalinity, 670 to 4000 mg/l. Among the conclusions reached were: (a) soil cover kept refuse cooler in cells and affected the rate of decomposition of milled refuse; (b) the mature phase of refuse decomposition was observed in a short time in cells without a soil cover; and (c) milling of refuse accelerated decomposition and caused production of higher concentrations of dissolved chemicals in leachate in the early phases of test cell operation.

Study Methods

A survey of DLPC water quality files yielded 123 leachate analyses from 54 landfills in 35 Illinois counties, collected during the period from June 1, 1971 to June 1, 1975 (Fig. 1).

Twenty-six sites were represented by one sample analysis. Two or more sample analyses were chosen from the re-

maining 28 sites. In cases where several samples were analyzed from one site, those most representative of the quality of the group were selected. Of the 123 samples, four (3.2 percent) were collected from leachate wells, six (4.9 percent) from collection systems, 26 (21.1 percent) from leachate ponds and 87 (70.8 percent) from leachate flows or seeps.

Most of the leachate samples were collected by DLPC field personnel located in three regional offices and were analyzed in one of three IEPA laboratories (Fig. 1). Standardization of sampling procedures and analysis techniques among regional offices and laboratories allows comparison of data from samples obtained throughout the state. Table 1 summarizes the sample preservation program which has been developed. With few exceptions, samples are transported to laboratories within 24 hours of collection. Incoming samples not meeting preservation requirements are not analyzed. Analytical methods, determination and reporting limits used by the IEPA laboratories for leachate analyses are summarized in Table 2.

Leachate Characteristics

Thirty-seven parameters were analyzed in the leachate samples chosen for study (Table 3). The choice of parameters for leachate analyses was based

Table 1 DLPC Sample Preservation Guide

Sample	Bottle	Preservative	Parameters						
1) Refrigerated	32-oz. plastic	Refrigeration-10°C	Alk	COD	Hdns	SC			
			NH ₃ -N	Cl	NO ₃	SO ₄			
			BOD ₅	Cr ⁺⁶	pH	TDS			
			B	F	PO ₄	TSS			
2) Metals	32-oz. plastic	20 ml, 1:1 HNO ₃	As	Ca	Fe	Mn	K	Ag	
			Ba	Cr(tot)	Pb	Hg	Se	Na	
			Cd	Cu	Mg	Ni	SiO ₂	Zn	
3) Special	6-oz. plastic	1 ml, 5N NaOH	Cyanide						
	32-oz. glass	4 ml, 1:1 H ₂ SO ₄	Oil						
	6-oz. plastic	2.1 ml, CuSO ₄ + H ₃ PO ₄	Phenol						

Table 2 Summary of Analytical Methods, Determination and Reporting Limits

Parameter	Method	Determination Limit	Reporting Limit
Alk(CaCO ₃)	Potentiometric	1.	x.
NH ₃ -N	Phenate	0.05	x.xx
As	AA	0.001	x.xxx
Ba	AA	0.1	x.x
BOD ₅	Incubation	1.	x.
B	Carminic Acid	0.1	x.x
Cd	AA	0.005	x.xx
Ca	AA	NA	x.x
COD	Reflux	4.	x.
Cl	Mercurimetric	0.5	x.
Cr ⁺⁶	Diphenylcarbazide	0.005	x.xx
Cr(tot)	AA	0.001	x.xx
Cu	AA	0.005	x.xx
CN	Pyridine-Barbituric Acid	0.002	x.xxx
F	SPADNS	NA	x.x
Hdms(CaCO ₃)	EDTA	1.	x.
Fe	AA	0.05	x.xx
Pb	AA	0.01	x.xx
Mg	AA	NA	x.x
Mn	AA	0.02	x.xx
Hg	AA	0.0001	x.xxxx
Ni	AA	0.05	x.x
NO ₃	Cadmium Reduction	0.02	x.xx
Oil	Extraction	1.	x.
pH	Electrometric	0.01	x.x
Phenol	Aminoantipyrine	0.005	x.xx
PO ₄	Stannous Chloride	0.01	x.xx
K	AA	NA	x.x
Se	AA	0.001	x.xxx
SiO ₂	AA	NA	x.
Ag	AA	0.001	x.xx
Na	AA	NA	x.x
SC	Wheatstone Bridge	NA	x.
SO ₄	Turbidimetric	1.	x.
TDS	Evaporation	1.	x.
TSS	Filtration	1.	x.
Zn	AA	0.01	x.x

All parameters expressed as mg/l except pH (units), and SC (micromhos/cm).

AA = Analysis by atomic absorption; NA = Not available; Ref.: IEPA Lab Methods Manual (1973).

both on the probability of detection of such parameters in raw leachate (called "indicator parameters"), as well as on parameters for which water quality standards exist. To a certain extent, the type of waste at a given site also determined the parameters selected. Heavy

metals and certain other trace elements were included because of their potential health hazards. Most chemical parameters analyzed were inorganic although it is recognized that organic compounds such as fatty acids, tannin and lignin can contribute significantly to leachate qual-

ity. Frequency of analyses ranged from 119 determinations for iron to two for oil.

The data in Table 3 show clearly the diverse nature of leachate quality. For example, the range of iron concentrations measured in 119 samples spans six orders of magnitude. In general, ranges of measured parameters coincide with values published in the literature, although there are some exceptions to this trend. The maximum concentrations of copper and iron were 1100 mg/l and 42,000 mg/l, respectively, while the maximum literature values were 9.9 mg/l and 5500 mg/l. The minimum concentration of chloride was 31 mg/l which corresponds closely to the minimum literature value of 34 mg/l. Among the metals, the highest concentrations were, in descending order, iron, copper, zinc and boron. The percentage of leachate samples in which a chemical parameter was determined in detectable amounts ranged from none for selenium (16 samples) to 100 percent for 20 parameters. Chemical parameters were measured in detectable amounts in over 50 percent of samples for 34 of the 37 parameters analyzed. Exceptions were arsenic (47 percent), hexavalent chromium (seven percent) and selenium.

Table 3 shows that, except for silica, mean values exceeded their corresponding medians for each parameter. The distribution of values about the mean thus exhibits positive skewness, indicating the influence of a few large values from a small number of samples on the mean leachate composition. This observation is also supported by the percentages in the last column of Table 3, which indicate that measured concentrations of all parameters, except pH, were higher than their corresponding mean value in less than half of the samples.

Arithmetic means of selected inorganic parameters from the leachate analyses of Table 3 were plotted as a linear graph of cumulative percent, based on mg/l (Fig. 2). Certain chemically related parameters were combined for purposes

Table 3 Summary of Inorganic Constituents in Leachate from Illinois Landfills

Parameter	Range Reported in Literature ¹			Range In DLPC Sample Group (123 Samples)			Median	Mean (\bar{x})	A	B	
Alk(CaCO ₃) ²	0	—	20850	0	—	13500	(68) ³	1225	2062	98.5	30.9
NH ₃ -N	0	—	1106	1.80	—	1250	(103)	82	158	100	39.8
As		NR		0.000	—	40	(38)	0.000	1.09	47.4	2.6
Ba		NR		0.2	—	9.0	(12)	2.25	3.05	100	41.7
BOD ₅	9	—	54610	87	—	6200	(13)	1500	2281	100	30.8
B		NR		0.42	—	70	(87)	4.7	9.0	100	27.6
Cd		NR		0.00	—	1.16	(42)	0.03	0.10	69	14.3
Ca	5	—	4080	23	—	3050	(67)	430	635	100	37.3
COD	0	—	89520	63	—	70740	(117)	4490	7996	100	35
Cl	34	—	2800	31	—	4350	(114)	562	773	100	40.4
Cr ⁺⁶		NR		0.00	—	0.06	(14)	0.00	0.004	7.1	7.1
Cr(tot)		NR		0.00	—	22.5	(45)	0.05	0.58	93.3	2.2
Cu	0	—	9.9	0.00	—	1100	(44)	0.05	25.2	86.4	2.3
CN		NR		0.000	—	0.08	(13)	0.028	0.030	76.9	38.5
F		NR		0.1	—	1.3	(17)	0.4	0.5	100	41.2
Hdms(CaCO ₃)	0	—	22800	100	—	7200	(68)	1600	2332	100	32.4
Fe	0.2	—	5500	0.9	—	42000	(119)	138	697	100	17.6
Pb	0	—	5.0	0.00	—	6.6	(113)	0.10	0.43	93.8	24.8
Mg	16.5	—	15600	12	—	1102	(65)	200	260	100	36.9
Mn	0.06	—	1400	0.00	—	678	(67)	9.2	27.5	98.5	26.9
Hg(ppb)		NR		0.0	—	30	(101)	0.3	1.2	59.4	19.8
Ni		NR		0.0	—	1.7	(28)	0.2	0.3	85.7	28.6
NO ₃		NR		0.00	—	1.8	(14)	0.10	0.46	78.6	35.7
Oil		NR		2	—	46	(2)	24	24	x	x
pH(units)	3.7	—	8.5	1.5	—	9.5	(92)	6.8	6.8	NA	51.1
Phenol		NR		0.17	—	6.6	(14)	0.77	1.94	100	28.6
PO ₄	0	—	154	0.00	—	52	(15)	1.80	5.16	86.7	13.3
K	2.8	—	3770	2	—	1920	(69)	150	270	100	33.3
Se		NR			ND		(16)	ND	ND	ND	ND
SiO ₂		NR		14	—	45	(6)	33	30	x	x
Ag		NR		0.00	—	0.24	(24)	0.01	0.03	58.3	29.2
Na	0	—	7700	15	—	8000	(67)	357	796	100	24.2
SC(umhos/cm)		NR		240	—	990000	(80)	6100	20540	100	6.3
SO ₄	1	—	1826	0	—	84000	(107)	153	1204	97.2	9.3
TDS	0	—	42276	990	—	594000	(68)	5346	20240	100	5.9
TSS	6	—	2685	21	—	3670	(8)	570	915	x	x
Zn	0	—	1000	0.0	—	250	(68)	1.7	12.1	97.1	14.7

¹USEPA, Environmental Assessment of Potential Gas and Leachate Problems at Land Disposal Sites (1973).²Concentrations are expressed as mg/l, except for Hg which is in ppb.³Number in parentheses denotes number of samples analyzed for the parameter concerned.⁴NA=not applicable; ND=not detected (16 samples); NR=not reported; x=less than 10 sample results.

A=Percent of samples in which parameter determined in detectable limits.

B=Percent of samples in which parameter determined in excess of \bar{x} .

of presentation of the data. Over 98 percent of the mean composition of inorganics in leachate was comprised of 6 groups of parameters: calcium plus magnesium, iron plus manganese, sodium plus potassium, total alkalinity (car-

bonate plus bicarbonate), sulfate, and chloride. Total alkalinity contributed more than 30 percent. The trace metal group of copper, lead, zinc, arsenic, cadmium, mercury, nickel and boron comprised less than one of the total. As

with most potable water analyses, the alkali metals contribute an important percentage to inorganics in leachate composition; however, percentages of iron plus manganese and sulfate are much higher than those found in po-

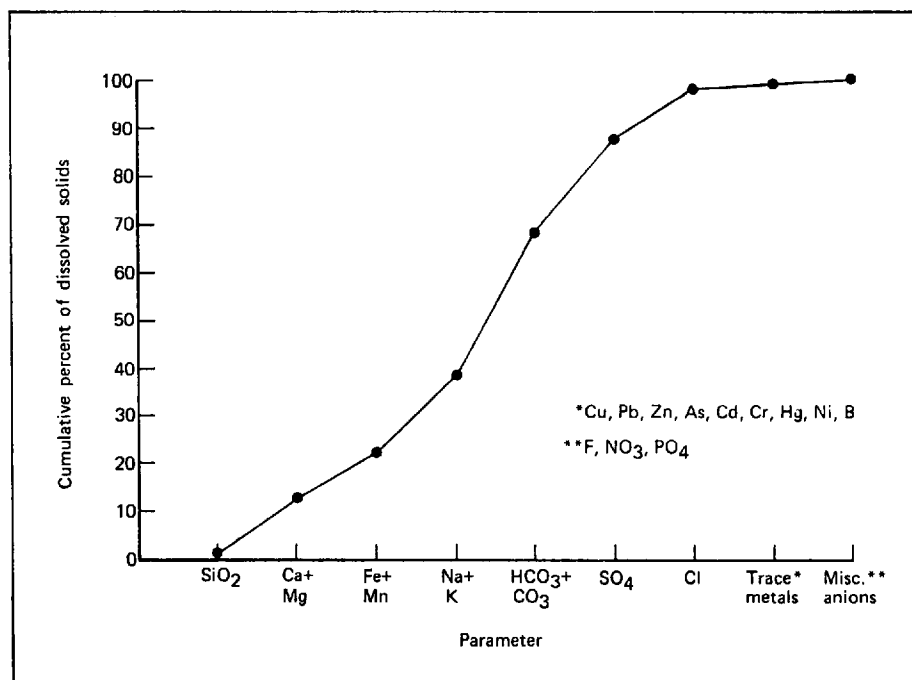


Figure 2. Major inorganic constituents of mean average leachate from landfills in Illinois, based on mg/l

Monitoring Indicators

Facilities for monitoring quality of ground and surface water in the vicinity of waste disposal sites serve not only as an early warning system to determine if pollutants are migrating away from a site, but also provide valuable information regarding the effectiveness of different protective systems designed to reduce leachate impact. Clark (1975) discussed positioning and construction of monitoring devices required on landfills in Illinois and included a list of twenty suggested chemical parameters which should be analyzed in samples collected for background data. Such analyses should include parameters sufficient to characterize most natural waters, while also containing constituents indicative of leachate pollution from landfilling activities. Following establishment of background water quality in the vicinity of a waste disposal site, which becomes a norm against which later changes in water quality may be measured, periodic routine sampling must be conducted. Ideally, all parameters originally determined in background samples would again be analyzed in subsequent samples. However, in the interest of time and economics, it has been common practice to analyze only a few select indicator parameters which can be likened to fingerprints for the more comprehensive analyses. Should excessive levels of an indicator be observed, more detailed analyses can be conducted to determine magnitude, directions, and reasons for a pollution problem.

Desirable characteristics for a landfill leachate indicator include the following: (a) availability—the indicator should be present in significant amounts in a wide range of waste types; (b) mobility—the indicator should be readily extractable from waste and dissolve in and move with the leachate; (c) persistence—the

table waters. As expected, the more soluble and mobile sodium and potassium ions comprised a somewhat greater percentage than those of calcium plus magnesium (15.7 vs. 13.1%) although the contribution of anions comprising the total alkalinity nearly doubled the percentage of either cation grouping.

Influence of Type of Waste and Cover Material on Leachate Quality

Leachate generated at a landfill where a single waste type makes up a large portion of the waste deposited or where undesirable cover material is used varies considerably in quality from the mean average inorganic leachate composition shown in Table 3. In one example (Table 4), as much as 5000 kg/day of brewery bottle-washing waste containing high concentrations of sodium hydroxide had been accepted with the municipal refuse for several years prior to the generation

of leachate. Here, the strongly caustic waste has raised the pH of the leachate, and thus prevented large amounts of the metals normally associated with refuse from entering solution. The high alkalinity and sodium and low total hardness values support this explanation.

In contrast, a second example indicates a leachate developed at a refuse landfill using incinerator ash and mine tailings as cover material. The potent leachate produced has a very low pH. This highly acidic solution will solubilize most of the waste and, as expected, the levels of dissolved solids, including metals and sulfate are unusually high.

The final example is indicative of the type of leachate produced by a site using high-permeability soil material as cover. High dissolved solids and COD values indicate that large amounts of contaminants are passing directly from the refuse through the cover material of the daily cells and are emerging from the sides and base of the landfill virtually unattenuated.

Table 4 Leachates Exhibiting Unique Chemical Characteristics Due to Cover Material and/or Waste Type Accepted

Parameter	Mean Leachate Composition (\bar{x})	Site Receiving up to 5000 kg/day Caustic Soda	Site Using Ash & Mine Tailings for Cover	Site Using Only Sand for Cover
Alk(CaCO ₃)	2062	13500	NM	2840
Ammonia N	158	430	NM	255
Boron	9.0	20	6.9	0.4
Calcium	635	25.5	NM	82
COD	7996	35950	9530	11971
Copper	25.2	1.07	1100	NM
Chloride	773	70	NM	1100
Chromium	0.004	NM	22.5	NM
Hdns (CaCO ₃)	2332	100	NM	1749
Iron	697	11.5	42000	900
Lead	0.43	0.95	5.3	1.2
Magnesium	260	30	NM	376
Manganese	27.5	9.0	678	NM
Mercury (ppb)	1.2	9.0	0.8	2.5
pH (units)	6.8	9.5	1.5	7.7
Potassium	270	270	NM	1285
Sodium	796	8000	NM	450
SC(umhos/cm)	20540	22200	NM	990000
Sulfate	1204	650	84000	475
TDS	20240	NM	156000	594000
Zinc	12.1	5.2	250	NM

All parameters expressed as mg/l except Hg(ppb), pH(units), and SC(micromhos/cm).

NM = not measured.

indicator should be resistant to ion-exchange, sorption, and chemical reactions as leachate passes through soils before entering water resources; (d) contrast—the indicator should be present in low concentration in background water samples in contrast to that in leachate; (e) analyticity—the indicator should be capable of being determined by a variety of laboratory and field analysis methods. To evaluate the potential effectiveness of certain commonly analyzed indicator parameters, several tests were conducted on the Illinois leachate data. The mean average inorganic composition of leachate (Table 3) indicates that ammonia, BOD, COD, chloride, copper, hardness, iron, manganese, oil and total dissolved solids were much higher than usually expected in ground water. Of these, copper is discussed with other heavy metals (see Fig. 5). Because

BOD, COD and oil are not routinely measured in ground water unless special conditions warrant, inadequate data were available to permit a comparison with leachate. Generally, filtration, fixation and decomposition of organics will diminish the use of BOD and oil as effective indicators. COD, on the other hand, might be a useful indicator, if the baseline data needed to determine the background level is available.

Figures 3a and 3b show the ranges of boron, iron, manganese, hardness, ammonia, chloride, sulfate and total dissolved solids in both the leachate data group and in unfinished Illinois ground-water supplies as reported by Larson (1963). To be valuable as a leachate indicator, a parameter should be distributed naturally over a narrow range of values, and the difference between concentra-

tions in the leachate and in background water quality should be as large as possible. Ideally, the concentration ranges observed in leachates should be mutually exclusive of those for ground water, that is, there should be no overlap of values in either leachate or native ground water for a given parameter.

Figures 3a and 3b indicate that overlapping of values does not exist for boron, iron, and ammonia; therefore, 100% of both leachate and ground-water samples are outside the overlap. Manganese overlaps narrowly, between 0.1 mg/l and 1.0 mg/l, but the majority of leachate and ground-water analyses are outside the overlap. In the range from 1000 mg/l to 2000 mg/l, overlapping is observed for dissolved solids, and about 85 and 90% of samples are outside the range for ground water and leachate, respectively.

Total hardness and chloride show mutual exclusivity over somewhat narrower ranges than do dissolved solids, iron, boron and ammonia. Total hardness concentrations are mutually inclusive in the range of 400 mg/l to 1000 mg/l and most of the samples are outside the overlap. For chloride, concentrations from 100 mg/l to 500 mg/l are mutual, with about 55% of leachate samples and 89% of ground-water samples lying outside this range. Sulfate, however, shows mutual exclusivity over only approximately 20% of its range. In addition, the difference between observed levels of sulfate in ground water measured against that of leachate for a given percentage interval is generally less than one-half order of magnitude throughout both ranges.

The above data, along with the availability and persistence of the discussed parameters, is summarized in Table 5 where each is evaluated and ranked as a leachate indicator. The overlapping concentration range and percent of samples outside the overlap were taken from Figures 3a and 3b. Persistence and availability of the subject chemical parameters were assigned qualitatively. An overall qualitative rank for each was

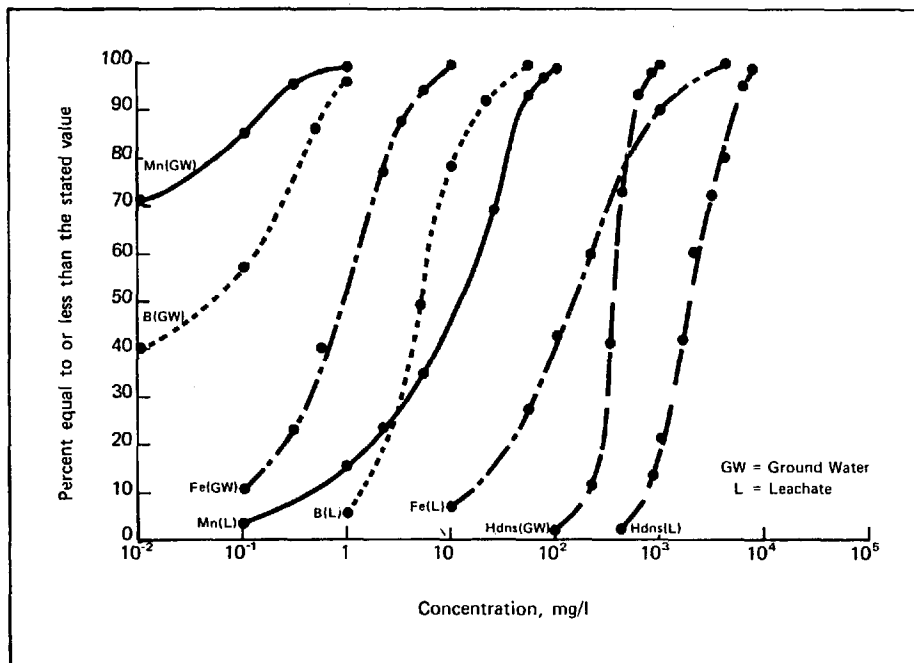
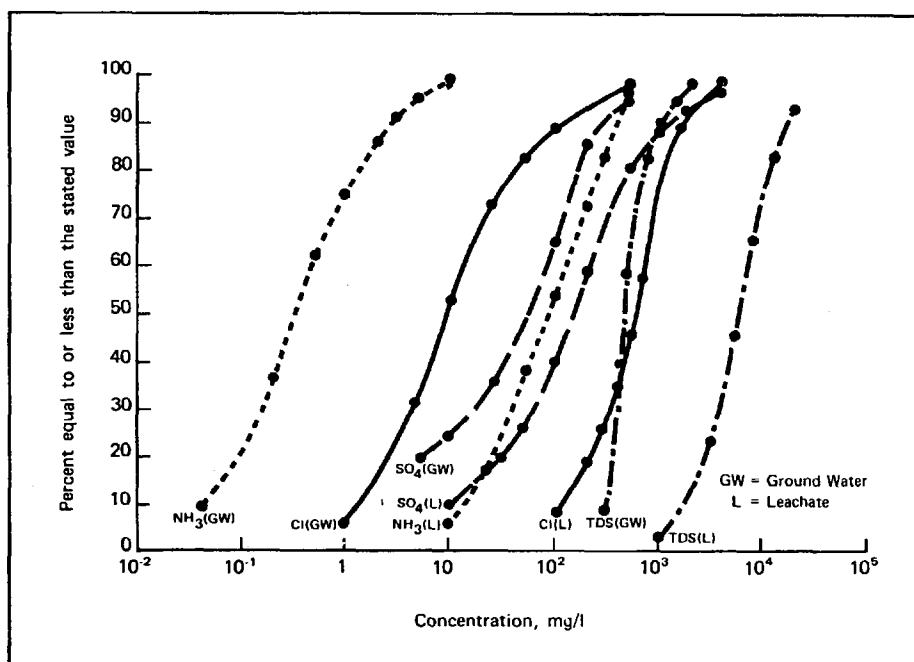


Figure 3a. Concentration ranges of selected inorganic chemical parameters in leachates versus ground water in Illinois: Manganese, Boron, Iron and Hardness



then determined, based upon consideration of all the criteria examined. Indicators were evaluated from average composition of leachate and ground water. They should therefore be used as a guide in investigation of ground-water pollution, rather than to designate which indicators apply to all cases.

The data show that each parameter has shortcomings within the prescribed criteria, thereby excluding its use as an ideal indicator. However, restrictions for certain parameters are more severe than for others. The data suggest that boron, iron, ammonia and total dissolved solids are the most useful, while chloride and total hardness are less reliable as leachate indicators. Reliability of chloride as an indicator increases when chloride concentrations are low (less than about 50 mg/l) in background ground-water samples. Total hardness should be a reliable indicator only in leachates containing over 1000 mg/l, unless background analyses indicate consistently low hardness levels. Manganese, although showing a relatively narrow overlapping concentration range, is less available and less mobile in waste than the other ions, so it has less value as an indicator. Sulfate, due to rather severe limitations within all the prescribed criteria, has the least value as a leachate indicator among the examined parameters.

Quality of Leachate and Natural Waters

Quality of leachate and natural waters were examined by plotting the major anions and cations on trilinear diagrams developed by Piper (1944). The graphs (Figs. 4a and 4b) include approximately 60 leachate analyses expressed in milli-

Figure 3b. Concentration ranges of selected inorganic chemical parameters in leachates versus ground water in Illinois: Ammonia, Chloride, Sulfate, Total Dissolved Solids

Table 5 Evaluation of Selected Inorganic Chemical Parameters of Leachate as Indicator Parameters in Illinois

Parameter	Overlapping Concentration Range (mg/l)	Percent of Samples Outside Overlap		Persistence and Mobility	Availability in Waste	Rank*
		Leachate	Ground-water			
B	none	100	100	very high	high	good
Fe	none	100	100	high	very high	good
Mn	0.1–1.0	95	86	moderate	moderate	fair
Hdms(CaCO ₃)	400–1000	78	75	NA	NA	fair
Cl	100–500	55	89	very high	very high	fair
NH ₃ -N	none	100	100	moderate	very high	good
SO ₄	10–500	20	25	moderate	high	poor
TDS	1000–2000	85	90	NA	NA	good

NA = not applicable

*good = should be applicable to a wide range of waste types and hydrogeologic conditions.

fair = may or may not be applicable, depending on waste type accepted and/or background levels.

poor = applicable only under special conditions.

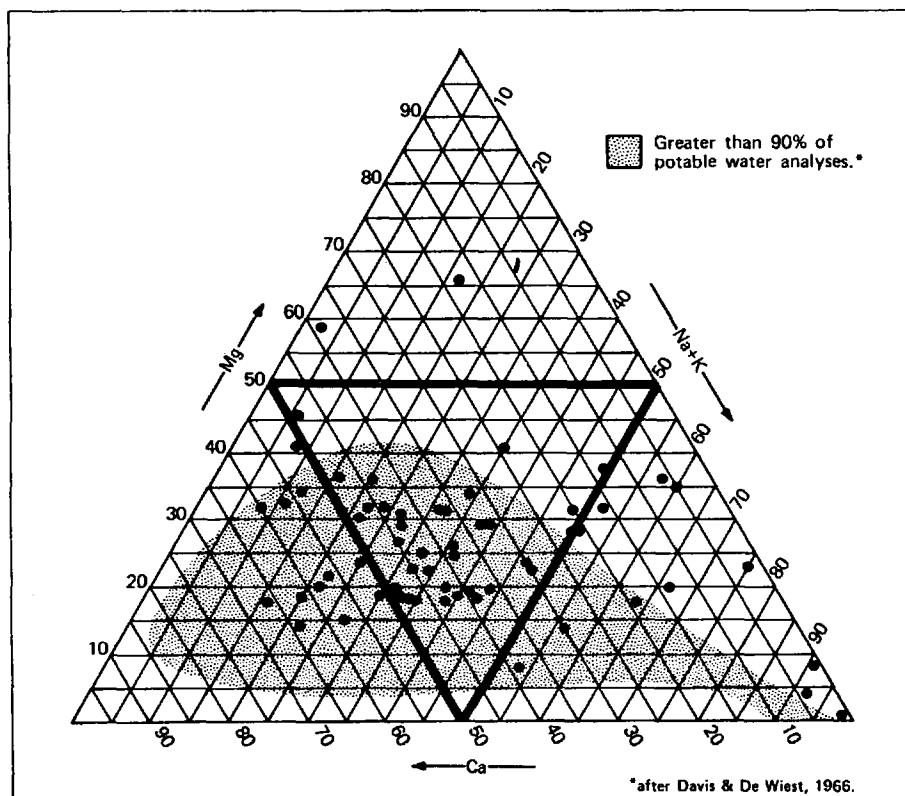
equivalents/liter, and the outline of the expected range of cation and anion values for potable waters, adapted from Davis and De Wiest (1966).

Approximately 73% of cation data for leachate samples falls within the range of potable waters. Calcium and sodium plus potassium, especially the former, appear to comprise the major portion of the cation composition. Analyses plotted outside the potable area show a slight trend toward sodium plus potassium enrichment, indicating possible effects of dominant waste types and ion-exchange reactions between these leachates and the soils through which they migrated before emerging from the fill face.

Approximately 92% of anion data for leachate samples falls within the area of potable waters. Carbonate plus bicarbonate are the major anion constituents. Few samples plot outside the boundaries of the potable water area, and these are generally sulfate or chloride rich. However, in only 3 leachate samples was the sulfate concentration greater than 50% of the anions examined. The reason for the significant amount of alkalinity present in leachate is not entirely understood. However, the following hypothesis may explain the reason for this observation. Alkalinity is produced by ions of weak acids which are not fully dissociated above a pH of 4.5. Carbonate and bicarbonate ions are the major contributors to alkalinity in most natural waters (Hem, 1970). During decomposition of organic wastes in landfills, a substantial amount of carbon dioxide is produced. This is then released both to the atmosphere through the landfill cover, and to the leachate. Carbon dioxide dissolved in water forms carbonic acid (H₂CO₃) which influences the total alkalinity of most leachates, although the contribution from other weak and/or organic acid salts (such as silicic, boric, phosphoric and tannic acids) is likely to be significant, also.

When only the major components of leachate and of natural waters are compared, it is evident that most leachates

Figure 4a. Percent in milliequivalents/liter, of major cations in leachate samples in Illinois



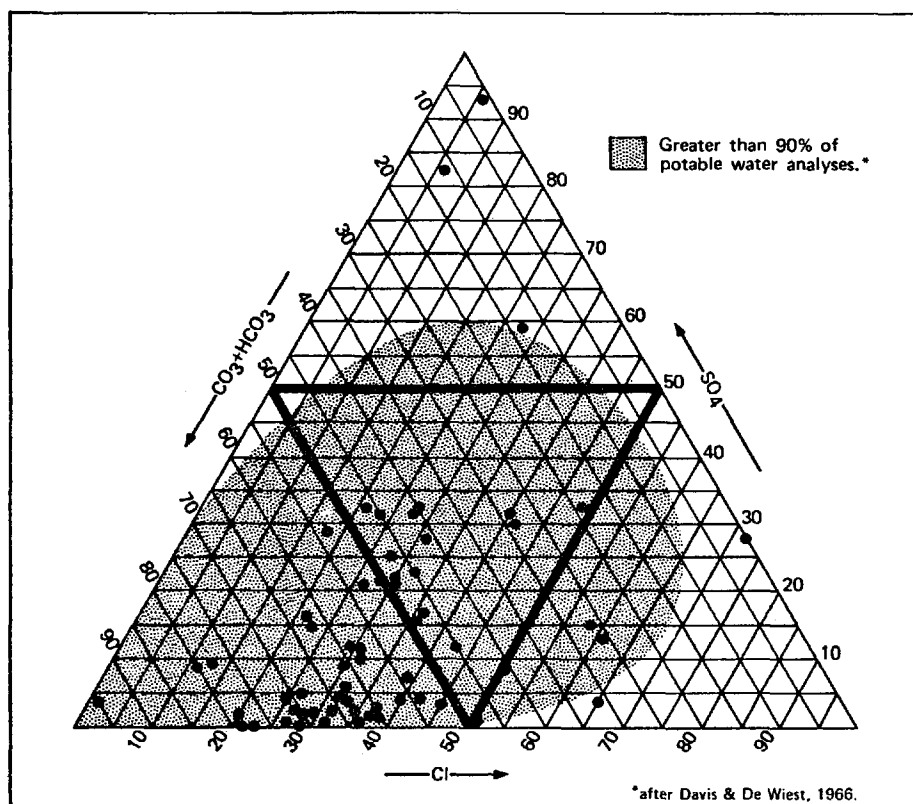


Figure 4b. Percent, in milliequivalents/liter, of major anions in leachate samples in Illinois

over this range. Concentrations of 10 to 50 micrograms/l were common for zinc, and a few samples had in excess of 5 mg/l.

Trace metals generally occur in very low levels in background water samples. The importance of different trace metals as leachate indicators can therefore be assessed better by comparing levels of metals in leachate analyses against existing water supply standards rather than against their natural background levels in surface or ground water. Figure 5 is a plot of 11 metals selected from the leachate analyses data and the percent which exceeded the corresponding maximum allowable 12-month average concentrations for that metal in Illinois public water supplies (Illinois Pollution Control Board, 1974).

When plotted, the data fall in three

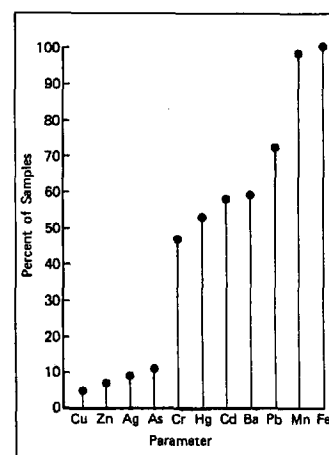
are within the concentration range of most potable waters. However, presence of other parameters not substantially found in potable water analyses—heavy metals, organics, microorganisms, odor, color and suspended matter, for example—are the major causes of the objectionable qualities of landfill leachate. Thus, those parameters in leachate having the greatest potential to impact a water supply's potability are generally not offset, in terms of total contribution, by those parameters having the greatest potential to impact public health.

Trace Elements in Leachate

The concentration of trace elements, particularly the heavy metal group, in landfill leachate is important because of

their potential health hazards. Although seldom present in large amounts, and generally comprising less than one percent of raw leachate composition (Fig. 2), heavy metals are frequently found in leachate considerably in excess of background levels of natural waters into which they migrate or are discharged. Durum and others (1971) discussed the minor element content of surface waters by examining more than 720 samples. They indicated that 98 samples had arsenic concentrations less than 50 micrograms/l, which is the USPHS drinking water standard. Cadmium was not present in detectable concentrations in 54% of the samples. For chromium and mercury, none of the samples was above USPHS drinking water standards of 50 and five micrograms/l, respectively. Lead generally occurred between six to 50 micrograms/l; in a few samples it was

Figure 5. Percent of leachate samples in which the indicated parameter was determined in excess of the maximum allowable 12-month average concentrations for that parameter



groups. Copper, zinc, silver and arsenic exceeded their corresponding standards in about 10% or less of the leachates analyzed. Silver and arsenic, when indicated in leachates, were present only in very small quantities. Copper and zinc, while present in the majority of samples analyzed (86 and 97% of samples, respectively), have relatively large maximum permissible concentrations, as high as 15 mg/l for zinc. Thus, although these elements are present in leachates, their value as leachate indicators is reduced because of their presence in only trace amounts, or because the allowable standard is large compared to their levels in most samples.

Chromium, mercury, cadmium and barium in leachate analyses plotted as a group which exceeded maximum allowable standards in approximately 40 to 60% of samples. Percentage of presence in detectable limits ranged from 59% for mercury to 100% of samples analyzed for barium. The presence of barium in all samples for which it was determined combined with its very low levels in natural waters possibly make it a better indicator of leachate contamination than has been previously recognized. Analysis of additional leachates for barium, generated under different hydrogeologic conditions would aid in establishing its reliability as an indicator. Lead, manganese and iron as a group exceeded maximum allowable standards in over 70% of the samples for which they were analyzed. For iron, all leachates for which it was analyzed exceeded the standard of 0.3 mg/l.

With the exception of iron, heavy metals are useful leachate indicators only in special instances because they are neither as available in most refuse, nor as mobile and persistent as other leachate constituents in landfill environments. As a group, the heavy metals may be useful to indicate water pollution when a single or dominant waste type of industrial origin, for example, is deposited in a landfill located in an unfavorable hydrogeologic area.

Conclusions

Study of analyses of inorganic constituents in 123 leachate samples collected from 54 Illinois landfills over a four-year period yields the following conclusions: (1) Chemical composition of leachate is highly variable and is generally similar to that published in the literature. Exceptions generally can be ascribed to dominant waste types accepted at a landfill and/or use of undesirable cover material. (2) With the exception of selenium, most of the chemical constituents analyzed in leachate were present in over half the samples analyzed. Twenty constituents were present in all samples for which each was analyzed. (3) Leachate composition is characterized primarily by six groups of parameters expressed in mg/l, in descending order: total alkalinity (bicarbonate plus carbonate), sulfate, sodium plus potassium, calcium plus magnesium, chloride, and iron plus manganese. (4) Among the metals, iron is most concentrated in leachate. Other significant trace constituents are copper, zinc and boron, but together they comprise less than one percent of the mean average leachate composition. (5) When major constituents are compared in terms of milliequivalents/liter, quality of leachate is not objectionable and corresponds closely to quality of most potable waters. Suspended solids, dissolved organic matter, heavy metals, color, odor and microorganisms are among the major causes of the objectionable nature of leachate and together may adversely impact public health. (6) Boron, iron, ammonia and dissolved solids appear to be reliable parameters for indicating pollution of ground water by landfill leachate. Chloride and total hardness may also be useful under certain conditions. Sulfate seems to be unreliable as a leachate indicator. (7) IEPA public water supply standards were exceeded for iron in 100% of leachate samples. For manganese, lead, barium, cadmium and mercury, more than fifty% of samples exceeded maximum allowable concentra-

tions. In descending order, chromium, arsenic, silver, zinc and copper exceeded maximum allowable concentrations in 47 to 5% of leachate samples. With the exception of iron, which should be applicable to a wide range of waste types and hydrogeologic conditions, heavy metals may be useful as indicator parameters when a single or dominant waste of industrial origin is deposited in a landfill of unfavorable hydrogeology.

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